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Measurement of neutron energy spectra behind shielding of a 120 GeV/c hadron beam facility

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Abstract

Neutron energy spectra were measured behind the lateral shield of the CERF (CERN-EU High Energy Reference Field) facility at CERN with a 120 GeV/c positive hadron beam (mainly a mixture of protons and pions) on a cylindrical copper target (7-cm diameter × 50-cm long). NE213 organic liquid scintillator (12.7-cm diameter × 12.7-cm long) was located at various longitudinal positions behind shields of 80- and 160-cm thick concrete and 40-cm thick iron. Neutron energy spectra in the energy range between 12 and 380 MeV were obtained by unfolding the measured pulse height spectra with the detector response functions which have been experimentally verified in the neutron energy range up to 380 MeV in separate experiments. The corresponding MARS15 Monte Carlo simulations generally gave good agreements with the experimental energy spectra.

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Keywords: Shielding experiment; NE213; Scintillator; CERF; Monte Carlo

1. Introduction

Estimations of high energy neutron production from materials and transmission through shielding are very important at high energy electron and hadron accelerator facilities because high energy neutrons have high penetrability through shielding and are main contribution to external dose. Modern Monte Carlo codes provide good predictions of radiation fluences in accelerator facilities even for complicated facility structures. However, accuracies are not well known for secondary neutron production and transmission due to high energy beams, especially above 1 GeV region because of lack of experimental data.

A 120 GeV/c hadron beam line facility CERF has been developed to provide a neutron calibration field outside the shield [1]. This facility has a simple structure of beam line and shielding, and a source term is clearly defined. In this work, neutron energy spectra outside the shield were measured as benchmark experimental data, and preliminary results are described in this paper.

2. Experiment

2.1. CERF facility

Fig. 1 shows the beam line of the CERF facility with 80- or 160-cm thick concrete for side shields and 80-cm thick concrete and 40-cm thick iron for roof shield. A copper target (50-cm thick, 7-cm diameter) can be placed at the two different locations, A or B as shown in Fig. 1. The beam line is inclined horizontally at approximately 2.1°. A positively charged hadron beam consisting of a mixture of protons (34.8%), pions (60.7%) and kaons (4.5%) with momentum of 120 GeV/c impacted on the target. The number of incident beam particles was measured relatively

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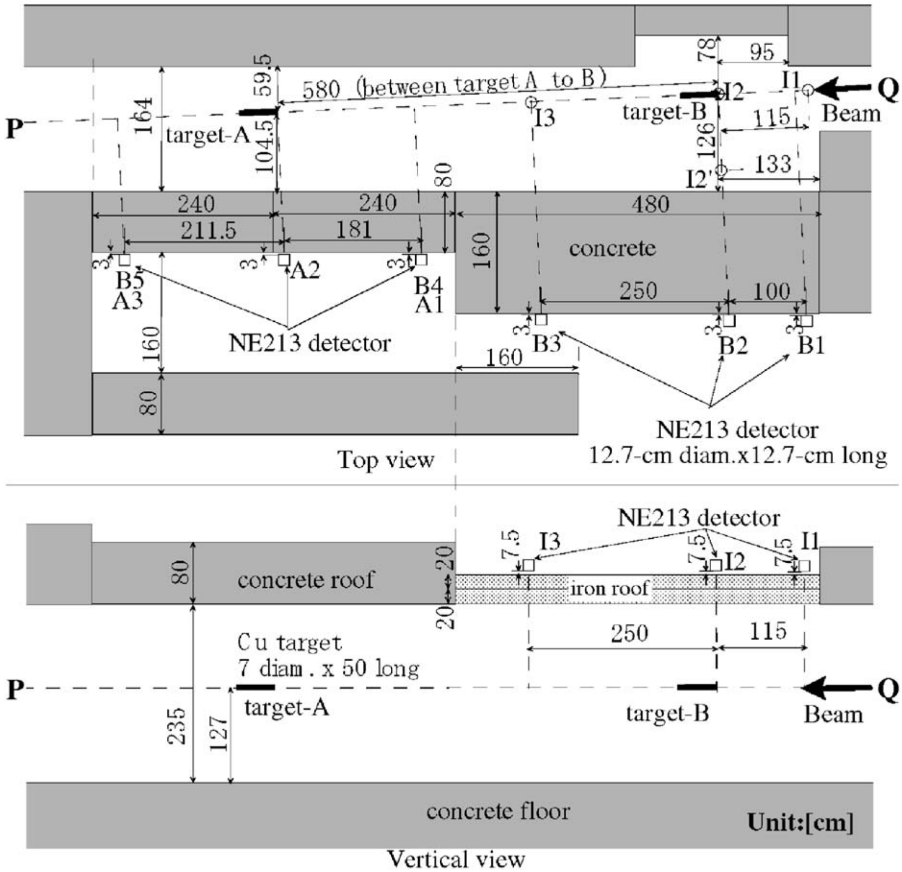

Fig. 1. Geometry of the CERF facility and detector locations.

Table 1
Densities of materials

Material	Density (g/cm^3)
Copper target	8.96
Iron roof (upper)	7.65
Iron roof (lower)	7.20
Concrete shield	2.40

Table 2
Composition of the concrete

	Wt%		Wt%
H	0.561	Si	16.175
C	4.377	S	0.414
O	48.204	K	0.833
Na	0.446	Ca	23.929
Mg	1.512	Ti	0.173
Al	2.113	Fe	1.263

Table 3
Detector locations and angles from beam incidence points of targets A and B

		Side concrete						Iron roof			
		80-cm thick			160-cm thick			40-cm thick			
Target A	Location	A3	A2	A1							
	Angle	40	90	133							
Target B	Location	B5		B4	B3	B2	B1	I3	I2	I2′	I1
	Angle	13		26	50	90	110	35	90	90	130

by a precision ionization chamber (PIC) beam monitor which is calibrated to absolute number of beam particles.

Densities of shielding materials and composition of the concrete shield are given in Tables 1 and 2, respectively.

2.2. Measurement

Neutron measurements were carried out using an NE213 organic liquid scintillator (12.7-cm diameter by 12.7-cm long), at different positions behind the shield as shown in Fig. 1. The detector locations and their angles from the beam incidence points of target location A and B are given in Table 3.

Two NE102A plastic scintillators (veto counters) of 5-mm thickness were used to reject charged particle events. A larger veto (30-cm $\times$ 30-cm) was located upstream of the NE213 detector mainly to reject muon background, and a smaller veto counter (15-cm $\times$ 15-cm) was in front of the NE213 to reject charged particles from the shielding wall or roof.

The electronic measurement circuit is shown in Fig. 2. The output signal from the NE213 detector was divided into two by a signal divider and fed to a CFD1 and an ADC. After the CFD1 selected pulses from the NE213 above threshold, charged particle events (especially muons) from upstream detected by the large veto counter (L-veto) were rejected by Veto1 in a coincidence module (Coin1). The next Coin2 rejected the events during the computer busy. The signals to ADCs from the NE213 were total or slow components which were generated by gating in the total or the slow (decay) region of the signal pulse. The signal from the small veto counter (S-veto) was fed to the ADC to get the total component of charged particle events from the shield. The L-veto signal was fed to the ADC without VETO1 only in the beginning of the experiment to determine the discrimination level of charged particles.

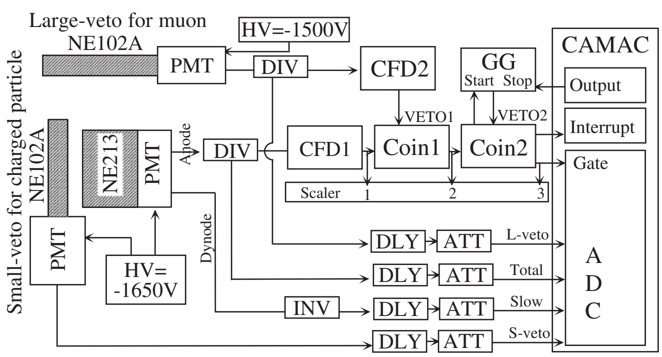

Fig. 2. Electronic measurement circuit. PMT: photo multiplier, CFD: constant fraction discriminator, COIN: coincidence, GG: gate and delay generator, DIV: signal divider, INV: inverter, DLY: delay, ATT: attenuator, ADC: analog to digital converter.

2.3. Analysis

Neutron events were selected by eliminating γ-ray events from the two-dimensional view of the total and slow components of the NE213 signals, and also by discriminating charged particle events detected by the S-veto. Neutron energy spectra were obtained by the unfolding method using the FORIST code [2]. The response matrix for 12–380 MeV neutrons for the unfolding was made from the response functions for this neutron spectrometer which have been experimentally investigated in the neutron energy range up to 390 MeV [3]. The uncertainty of the response function is 15%.

3. Calculation

Monte Carlo calculations were performed using the MARS15 code [4] with the geometry as shown in Fig. 1 to compare to the experimental neutron energy

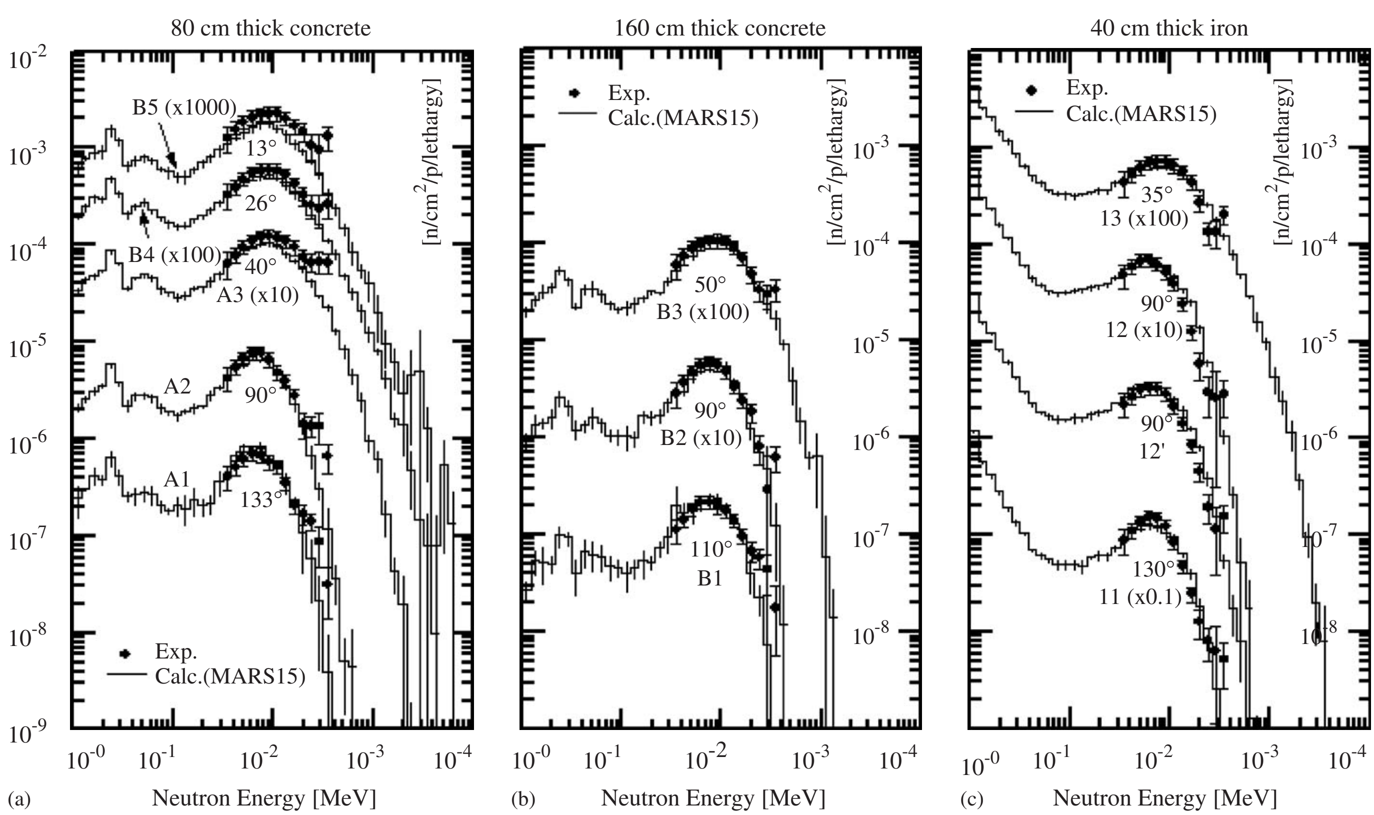

Fig. 3. Experimental neutron energy spectra compared with the MARS15 Monte Carlo calculation results: (a) behind 80-cm thick concrete (b) behind 160-cm thick concrete; and (c) behind 40-cm thick iron.

spectra. Neutron tracklengths in the cylindrical detector volumes defined behind the shielding were collected in an energy range above 1 MeV. No variance reduction technique was used. Low energy neutron transport below 14.5 MeV was performed using the MCNP option in MARS15 code.

4. Results and discussion

Fig. 3 shows measured neutron energy spectra behind 80- and 160-cm thick concrete, and 40-cm thick iron both for target locations A and B obtained by the unfolding method. A broad peak of cascade can be seen around 80 MeV in all energy spectra. Since the maximum neutron energy of the response matrix is 380 MeV, the experimental data above that energy could not be obtained. Bumps in the fluxes around the maximum energy can be seen in the spectra at forward angles since neutrons in the energies of higher than 380 MeV, of which fluxes are not negligible, contributed to the results of maximum energy group in the unfolding process.

MARS15 calculation results are also shown in Fig. 3. Although slight discrepancies between the experiment and the calculation can be seen at forward angles such as the A3, B4 and B5 locations after 80-cm thick concrete, the calculated spectra generally agreed very well with the experimental spectra within the experimental errors.

5. Conclusion

High energy neutron measurements were performed behind lateral shields of concrete and iron using a 120 GeV/c hadron beam at the CERF facility, and energy spectra were obtained by an unfolding method from 30 to 380 MeV. The corresponding simulation using the MARS15 Monte Carlo code generally agreed well with experimental spectra.

Acknowledgments

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